Optical High Speed Communications for HAPS

Experiments, Prototypes, and Studies,
by German Aerospace Center,
Institute for Communications and Navigation

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- Scenarios for Optical HAP DataComms
- Activities in Optical High-Speed HAP Communications
- Heritage: CAPANINA project
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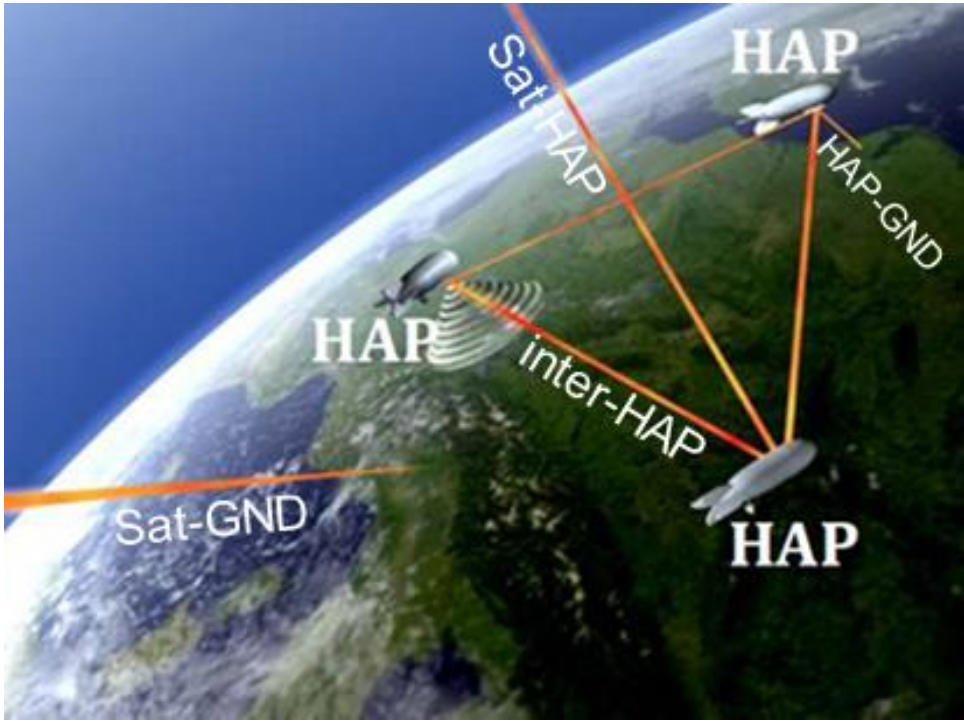
Optical High-Speed Links for HAPS – Scenarios overview

- High-Speed Inter-HAP-Links: setting up a high-speed network in the skies serving mobile users: ~10Gbps optical links
  - Example use case: HAPS as access point for mobile comms infrastructure
- High-Speed HAP-GND-Links: for EO-Telemetry onboard HAPS, or for HAP-network connectivity to ground
- High-Speed optical Payload and Telemetry Downlinks from LEOs via HAPS as Relais
  - avoiding the hurdle of cloud blockage. Downlink from HAP to GND by short-range RF link
- Quantum Key Distribution on continental scale
- Backhaul from EO-HAP via GEO-relais:
  - enables EO and Telecom-HAPS BLoS communications



Stratospheric Laser Communications Activities
Developments relevant for stratospheric laser comms

Google (Loon)	130 Mbps bidirectional air-air (Balloon)
DLR (CAPANINA/OSIRIS)	1 Gbps unidirectional air-ground (Balloon) and up to 10 Gbps unidirectional LEO-GND
Mynaric/Facebook	10 Gbps bidirectional air-ground (Cessna)
Facebook	100 Gbps bidirectional air-ground (Cessna)
Airbus (LOLA)	50/2 Mbps bidirectional air-GEO
Tesat (LCT)	1.8/5.6 Gbps bidirectional LEO-GEO/LEO-GND

and further developments for aeronautical laser communicaitons by MIT, DARPA, US Air Force, Airbus Defence and Space, General Atomic, DLR, Mynaric, Zeiss, …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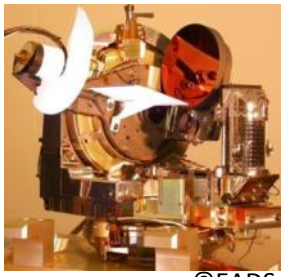
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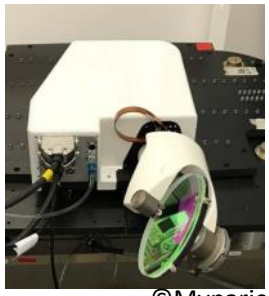
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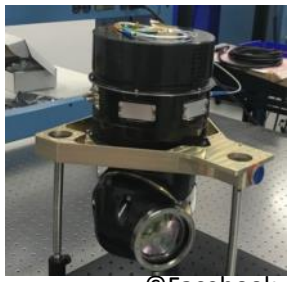
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Horwath et al., "Test results of error-free bidirectional 10 Gbps link for air-to-ground optical communications," Proc. SPIE 10524, 2018.
Zech et al., "LCT for EDRS: LEO to GEO Optical communications at 1,8 Gbps between Alphasat and Sentinel 1a," Proc. SPIE 9674, 2015.
Chen et al., "Demonstration of a bidirectional coherent air-to-ground optical link," Proc. SPIE 10524, 2018.
Vaillon et al,. "Optical communications between an aircraft and a geo relay satellite: design and flight results of the LOLA demonstrator," Proc. Of ICSO, 2008.
Moision et al., "Demonstration of free-space optical communication for long-range data links between balloons on Project Loon," Proc. SPIE 10096, 2017.
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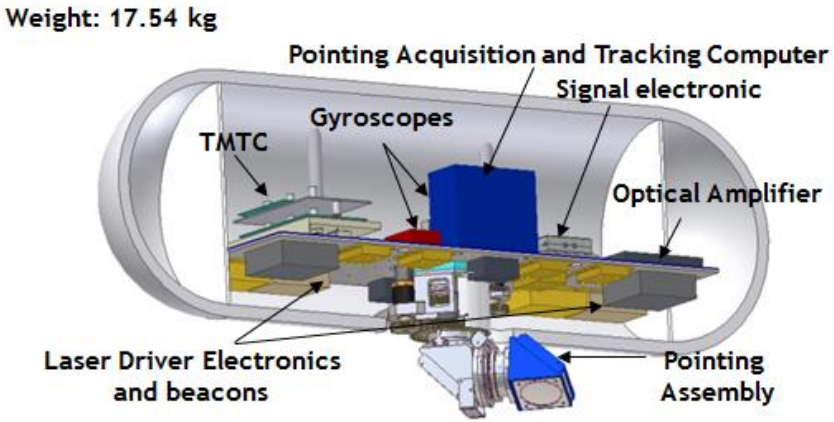
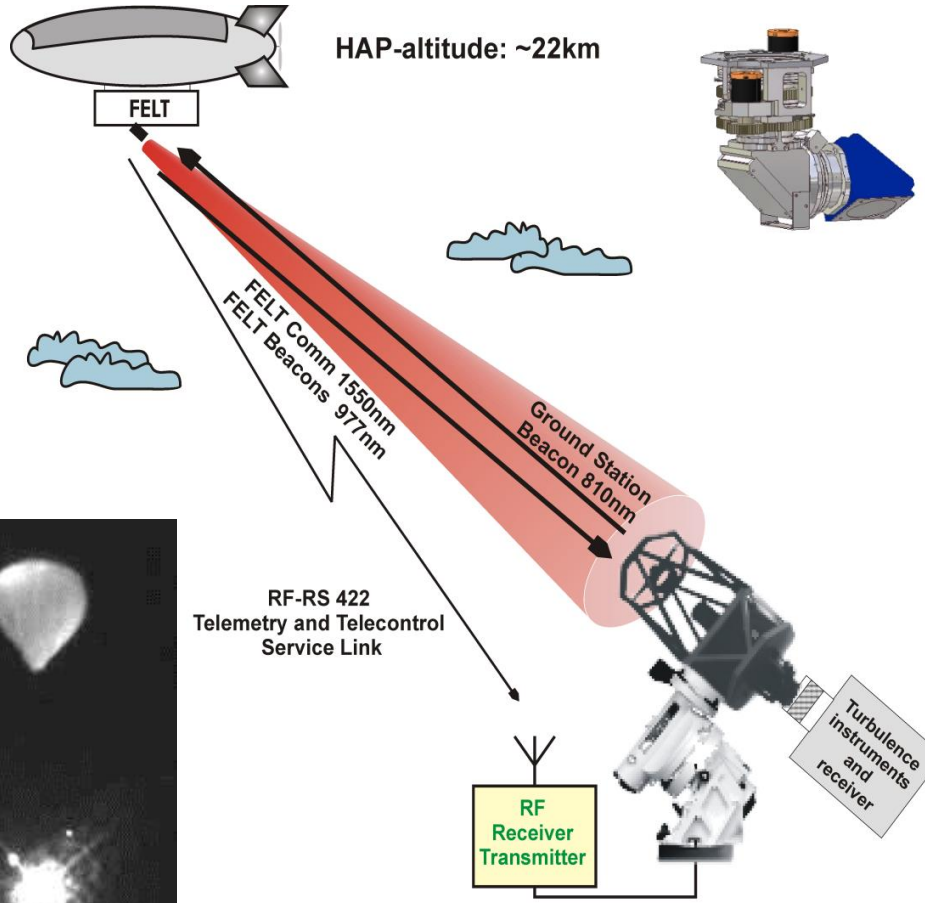
CAPANINA-Heritage: 1.25Gbps from 64km distance @ 24km altitude





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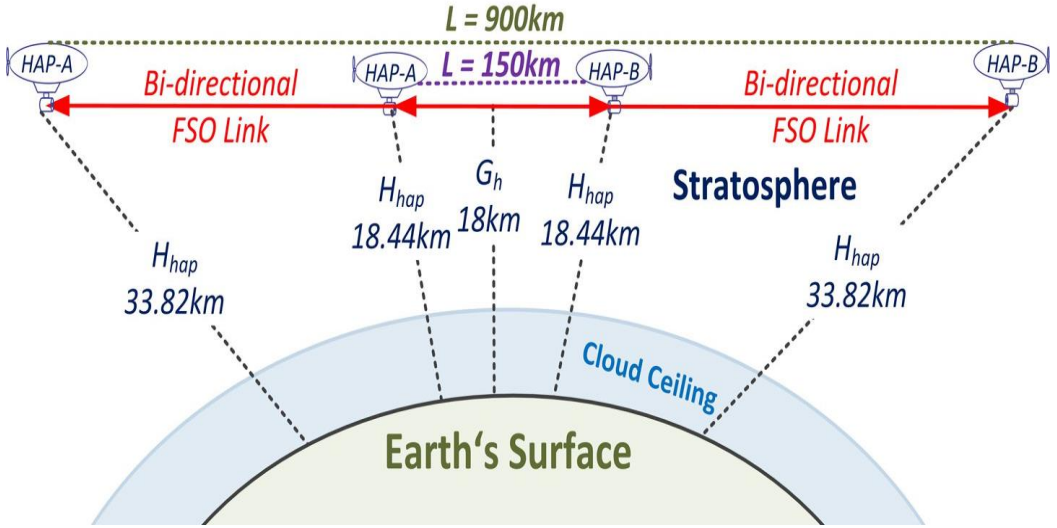
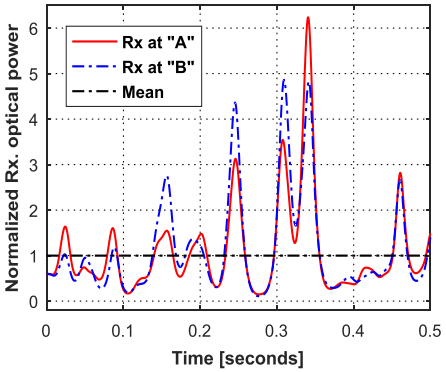
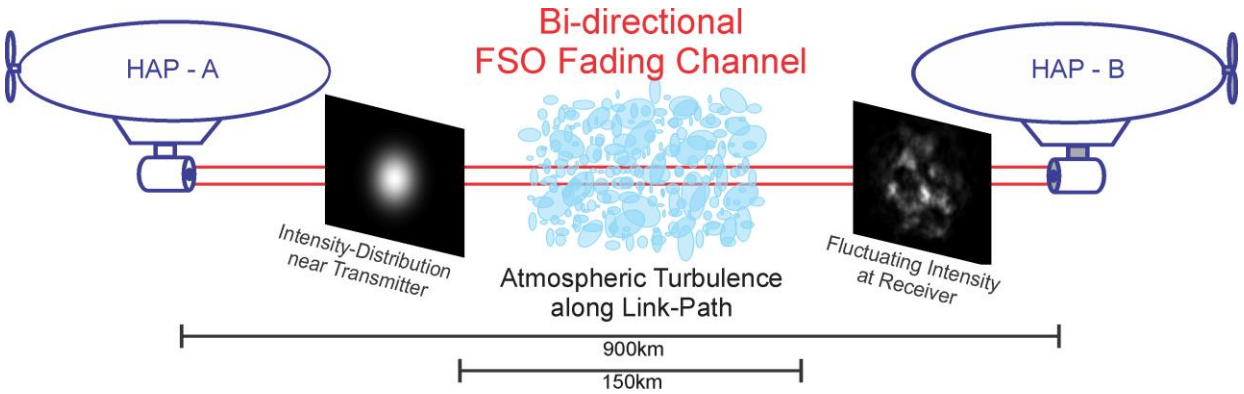
Inter-HAP FSO Scenario above cloud layer: Distances, Heights, IRT-Scintillations

- Impact of **Clouds** → Link Blockage → min-. link height
- Impact of **atmospheric index of refraction turbulence (IRT)** along the propagation path
  → Intensity fluctuations at Rx (***Scintillations)***
- **Strength of Fades** → given by IRT and link length
- **Temporal variations** → due **to stratospheric winds orthogonal** to the link
- ***Correlation*** of signal fading under certain conditions (reciprocity)





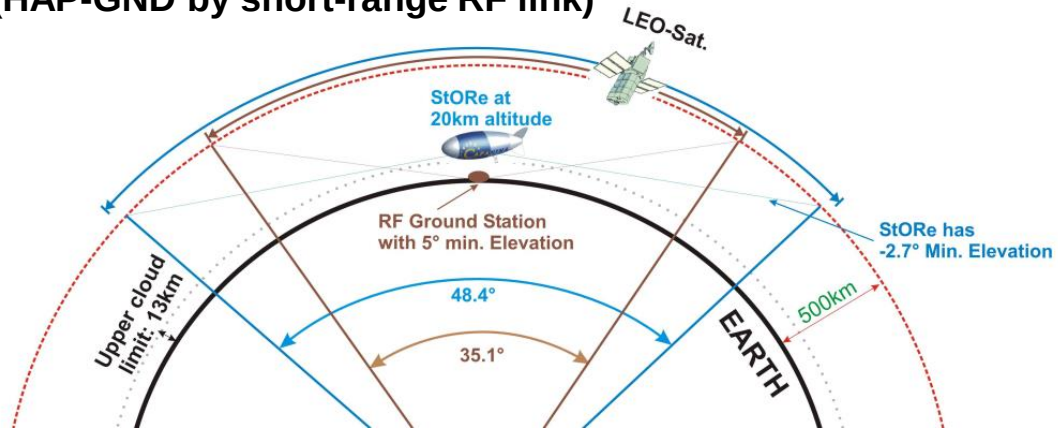
typical long-range Scenario:
PSI = 1.0, τ= 10ms

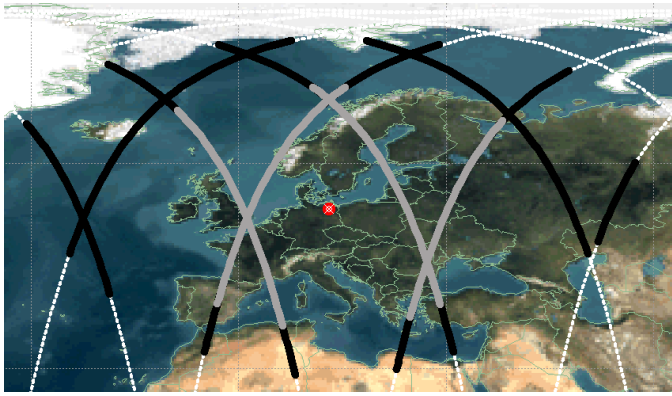


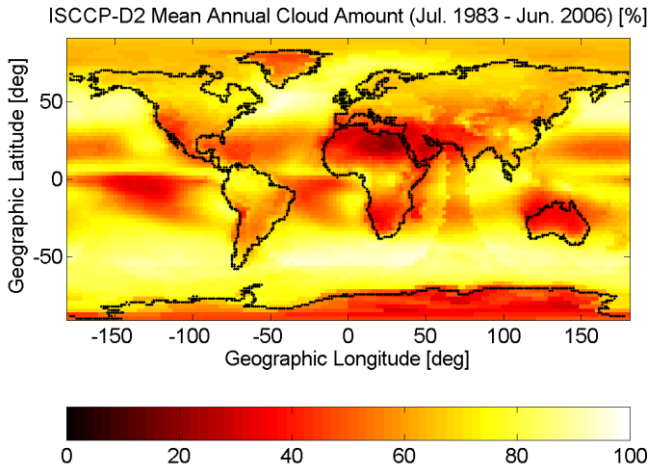
Bi-directional inter-HAP FSO link at stratosphere between HAPs A and B

HAPS as Relais for Opt. LEO-Downlinks:

Less Atmos. Attenuation, Increased Visibility Lemgth, and No Cloud-Blockage
→ results in much higher mean throughput than direct-to-earth downlinks
(HAP-GND by short-range RF link)

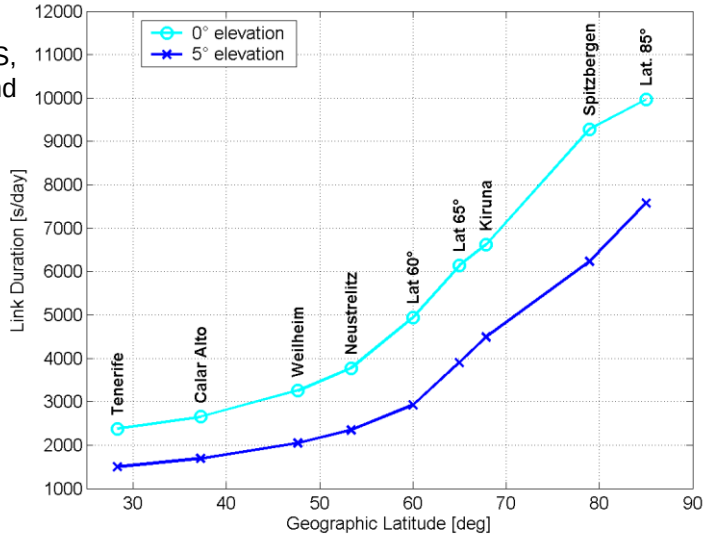






frequent cloud-blockage, dependent on OGS-location

0° elev. possible to HAPS,
5° is minimum to ground



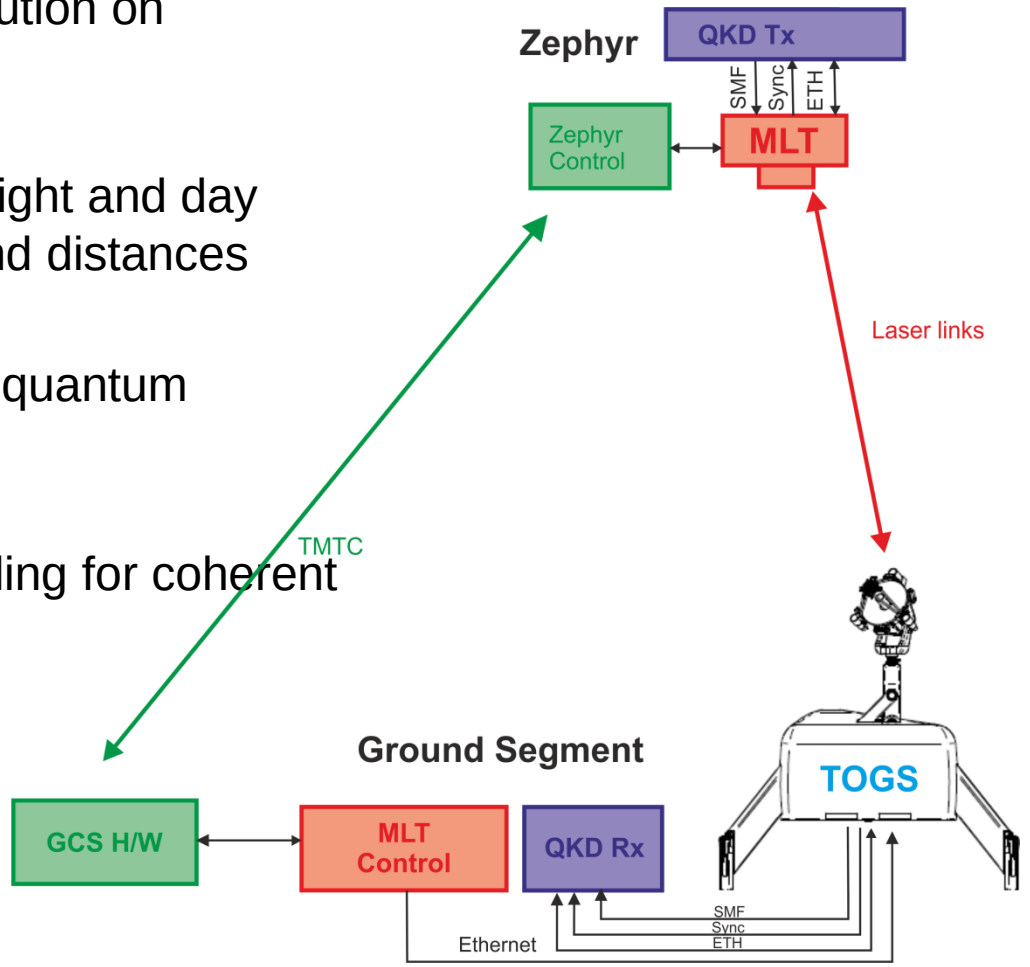
HAPS for Quantum Key Distribution

Feasibility Study Zephyr with Optical Ground Station

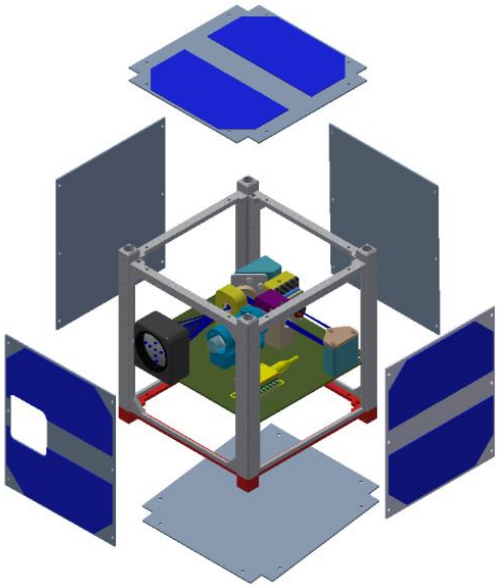
Source: Airbus

- Use case HAPS: secure key distribution on continental scale
- Challenges: SWaP requirements; night and day operation; Different flight heights and distances
- Use of Laser links for classical and quantum communication
- Design of ground station fiber coupling for coherent receiver and polarization analysis
- Design of low SWaP QKD payload

→ QKD from HAPS is feasible



CubeSat Optical Terminal Adaptation for HAP Downlinks : small and light weight

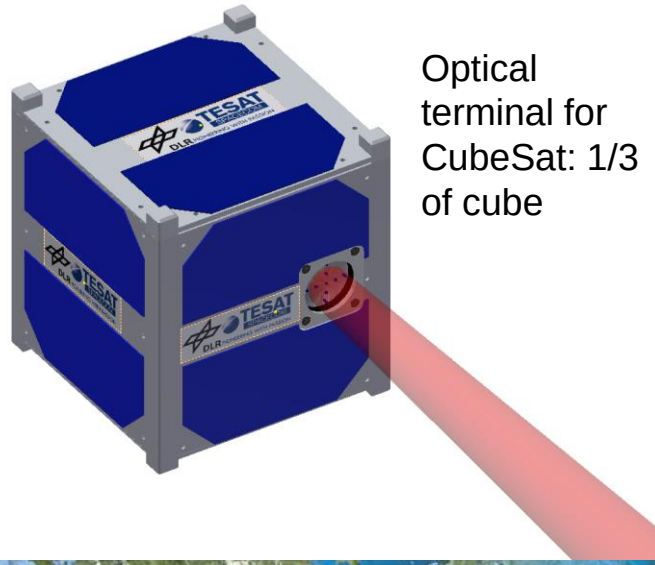


- Miniaturized OSIRIS generation for cubesat platforms
- Combination of body-pointing and fine-steering mechanism
- Demonstration on CubeSat in 2019

- Key system parameters
  - Size: 90 x 95 x 35 mm (~0.3U)
  - Weight: < 300g
  - Power consumption: < 8W
  - From LEO: Downlink to 60cm OGS: ~ 50Mbps
  - → From HAP: up to 5Gbps

→ *on HAP implement additional coarse beam steering assembly*

weight estimate	size estimte
O4C:300g LET1G: 50g housing: 80g periscope: 800g	0.35l + 0.1l + 1l



Optical terminal for CubeSat: 1/3 of cube

Summary and Recommendation

- Free-space laser communication is feasible for diverse HAPS scenarios
- HAPS can serve as basis for quantum key distribution on continental scale

- requirements of all HAPS scenarios on the laser terminal strongly overlap → feasible to cover all scenarios with a single core terminal setup and appropriate modifications of CPA optics

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